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Mass Spectrometry (MS) and Ultra-fast Mass Spectrometry (UFMS)

A Disruptive Technology Driving the Expansion of MS Market

A Frost & Sullivan White Paper

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I. Executive Summary

Mass spectrometry (MS) is a key analytical tool applied to a broad range of applications and business sectors. MS measures the mass to charge ratios of molecular ions and when fragmented generates a mass spectrum which can be used in identification and verification for pure solutions or complex mixtures.

MS Market Products

SINGLE QUADRUPOLE LC-MS	Single Quadrupole as a mass analyzer and liquid chromatography (LC) as a separation technique
TANDEM QUADRUPOLE (TQ) LC-MS	TQ LC-MS includes 2 Quadrupole mass analyzers and a collision cell for fragmentation; Includes both Triple Quad and Ion Trap System
TIME-OF-FLIGHT (TOF) MS	TOF-MS includes TOF LC-MS, TOF/TOF, and Q-TOF
GAS CHROMATOGRAPHY (GC)-MS	GC-MS includes Single Quadrupole, Triple Quadrupole, and Q-TOF systems
MALDI-TOF MS	Matrix-assisted Laser Desorption/Ionization TOF MS
ICP-MS	Inductively Coupled Plasma MS

Note: MS is mass spectrometry; LC is liquid chromatography

Key Findings

MS Technology Segment:

- Tandem liquid chromatography-mass spectrometry (LC-MS) had a sales volume of $1,102.6 million in 2015. Applications focused on increased sensitivity & specificity.
- Increased adoption of Matrix Assisted Laser Desorption/Ionization (MALDI)-TOF in clinical microbiology due to its simplicity, reproducibility and the availability of interpretative algorithms.

MS Market Segment:

- Pharmaceutical industry continues to dominate MS sales as biopharma plays a greater role in clinical therapeutics.

Key Driving Factors for MS Demand:

- Highly regulated food safety analysis
- Increase in government funding for research activities
- Increased new product launches by major participants
- Advances in mass spectrometry technologies

MS Market End Users

ACADEMIA AND GOVERNMENT	Academic university research labs and government research institutions
PHARMA/BIO	Pharmaceutical (Drug discovery, combinatorial chemistry, pharmacokinetics, drug metabolism), biotechnology/biopharmaceuticals (analysis of proteins, peptides, oligonucleotides), and contract research organizations
INDUSTRIAL SECTORS	Chemical, oil and gas, polymer, and semiconductor/electronics industries
APPLIED MARKETS	Agriculture and food, environmental testing, forensics, hospitals, clinical analysis

II. Adoption of Mass Spectrometry

The MS market generated revenues of US$3.02 billion in 2015 which is estimated to reach US$5.03 billion by 2022. The significant growth rate of the global MS market signifies its accelerating demand in this technologically-dynamic market with broad applications and diversified end-user bases.

Asia Pacific (APAC) and India are expected to grow with significant CAGR of 9.6% and 20.0% respectively within the same period despite North America retaining the largest MS market share. This is due to the increasing use of MS as the primary detection tool in the pharmaceutical industry for drug discovery pipeline and for quality assurance/ quality control purposes. China also shows an increased trend in applying MS in food safety and environmental monitoring programs.

The growth in global MS sales takes into account core routine technologies such as triple quadrupoles, recognized for delivering high detection sensitivities and robust performance, together with an increased need for high mass accuracy technologies such as the Quadrupole-Time of Flight (Q-TOF) mass spectrometry. Also, there is a strong indication that MALDI-TOF will have a higher impact in routine clinical pathology laboratories as a result of the inherent simplicity, speed and sensitivity in MALDI-TOF analysis.

Key Takeaway

- Continuous technological advancements in TQ LC-MS and Q-TOF drive greater market growth.
- Growth in the all business sectors particularly pharma with a greater acceptance of MS in routine clinical pathology.
- North America & Europe are mature markets, whereas APAC and the rest-of-the world hold a significant potential for rapid growth in coming years.

Drivers for Adoption of MS Market Growth

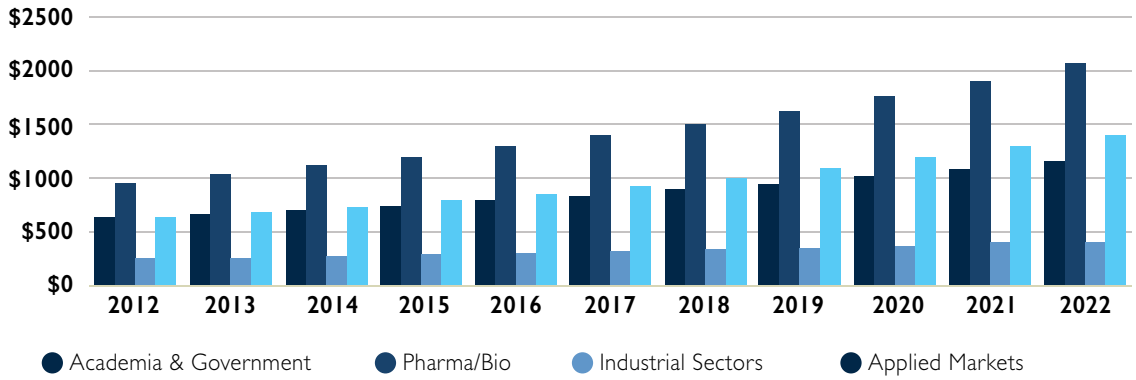
MS USAGE IN APAC SPURS MARKET GROWTH	• APAC being a developing economic region offers an attractive growth perspective for MS industry. Some of the important factors include increase in government research funding and expansion of life sciences market. • Established markets such as North America and Europe turn to APAC for R&D outsourcing activities due to the surge in demand from pharma & biotech industries, and the increasing research interest in APAC
TECHNOLOGICAL ADVANCEMENT OF MS INSTRUMENT EFFICIENCY & DESIGN	• Miniaturization of MS instruments has been an important innovation in the MS market meeting a clear need for a lower impact on lab space and simple MS detection applications. • MALDI-MS applied to microbe identification continues to have a high impact in routine clinical microbiology laboratories. • Advances in next generation triple quadrupole technology has delivered a step change not only in higher sensitivity and library based identification but also in the enhanced capability in monitoring a higher number of compounds in a single analysis. Such innovations result in higher data quality and better tools to help meet regulatory needs using expanded compound panels.
DEVELOPMENT OF RIGOROUS SAFETY REGULATIONS IN APAC CALLS FOR MS ADOPTION	• The implementation of stringent safety regulations and policies in APAC will drive the pharmaceutical, environmental, and food & beverage testing industries to adopt MS for a quick and efficient outcome • The increase trade flows and cross-border efficiencies in APAC leads to increased regulatory pressure for improved food and consumer safety
MERGERS, ACQUISITIONS AND PARTNERSHIP BETWEEN MS PROVIDERS AND OTHER COMPANIES	• Innovations in MS, coupled with an increased adoption of the technology in the life sciences and clinical analysis sectors, are creating rich opportunities for mergers and acquisitions in the global market. • MS vendors may collaborate with other R&D companies to integrate and tailor the MS technology to be a game-changing solution for specific industries

III. Current Market Dynamics and Primary Challenges of Mass Spectrometry

MS Market Revenue Forecast by End-Users

The Pharma/Bio and Applied Markets segment contributed the most towards the mass spectrometry revenue. The need for mass spectrometers in diverse business segments has increased due to a greater focus on research and testing. However, particularly in academia, there is a degree of uncertainty in the likely growth of mass spectrometry as government funding is less predictable resulting in delays to capital expenditure.

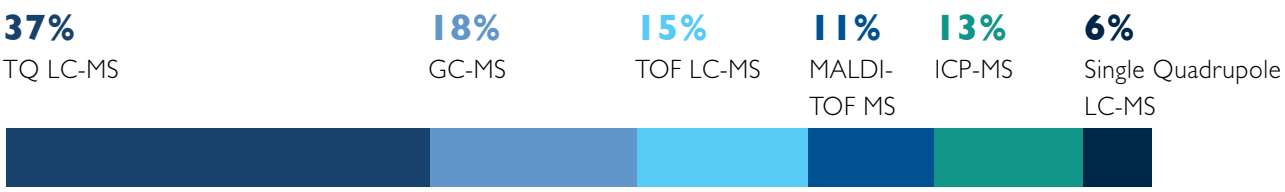
MS Revenue Forecast by End-Users, Global, 2012-2022



MS Product Segment Analysis

TQ LC-MS is very well established given its inherent high sensitivity and robust detection. Due to its ability to accurately quantitate low trace levels of components in complex matrices, the technology is increasingly being adopted by the environment and food testing applications and also in the clinical analysis sector.

Revenue Breakdown of MS Products, Global, 2015



Perceived Barriers to MS

The potential of MS market in APAC is not yet fully realized due to factors such as high expenditure and instruments' long replacement cycle which has constricted MS users in acquiring new instruments. MS remains expensive and cost-prohibitive for many laboratories despite the effort to widen the instrument's pricing range to further enlarge the customer base.

BARRIERS	DESCRIPTION
Complex technology that requires specialist skill	• No drive to adopt new and complex technology that requires a higher skill set. • There is still a perception that MS technology is within the domain of cutting edge research laboratories.

KEY LEADER'S PERSPECTIVE

MS offers high sensitivity and specificity' but that 'despite the advantages, there has been a slow uptake in the clinics due to the human and capital investment

Rohit Shroff, Product Manager at
Tecan Schweiz AG

Mass spec is a very powerful technology, but in general quite complex requiring highly sophisticated equipment as well as mass spec experts to analyze the data and build the relevant databases for routine use.

Bert Top, Senior Marketing Manager at
BioMeriux

Skill gap in handling of MS	• As laboratories increasingly need to balance investment with outcomes, training users in multidisciplinary techniques needs focused, easy to use software applications. • Near zero practical experience for many technicians.

KEY LEADER'S PERSPECTIVE

It is a significant barrier for any laboratory to adopt new technology and workflow. We know that the only way to break this barrier is by providing a turnkey solution, as well as making the workflow similar to what people are conventionally used to, such as HPLC and clinical analyzer."

Atsuhiko Toyama, Marketing Manager at
Shimadzu Corporation

BARRIERS	DESCRIPTION
Labor-intensive and time-consuming process	• MS labs generate information rich data content. Reviewing MS data takes time and resource particularly in high throughput environments

KEY LEADER'S PERSPECTIVE

Current labor-intensive and time-consuming process of mass spectrometry is one of the major hurdles that have prevented labs from adopting MS at a much faster rate.

Victoria Zhang, the Founding Chair of the newly formed Mass Spectrometry and Separation Sciences (MSSS) Division at AACC

Front-end automation…is only half the battle'. The volumes of data generated in even a small laboratory are immense. 'Taking an admittedly limited case - looking at 100 samples a day for 50 compounds, where each compound is monitored by two ion transitions - means that someone's job is to look through 10,000 chromatographic peaks - individually, manually - just to get through one batch of results. Scaling that up to a more real-world example thousands of samples a day; 150 compounds - and the volume of work becomes staggering, and difficult to consistently review, every time, on time

Jim Edwards, VP Product Manager of Indigo BioAutomation

BARRIERS	DESCRIPTION
Cost	• The real or perceived cost of MS poses as a major barrier in its deployment.

KEY LEADER'S PERSPECTIVE

While the cost of the instrumentation may be perceived as high in an absolute sense, in terms of its relative value and return on investment, there are medically necessary tests, critical to patient care, for which MS is uniquely capable

Randy Julian CEO of
Indigo BioAutomation

Pairing hardware automation such as this to advanced data handling and software automation is the best way to reduce end-to-end costs, while maximizing productivity and quality.

Randy Julian

Designing systems that empower managers and users to unlock the value of the mass spectrometer is really important to any business delivering better data and greater capability. Driving instrument design to deliver robust detection in 24/7 environments reduces maintenance cycles and service costs. It makes a real difference to the cost effectiveness of any investment and gives a competitive edge."

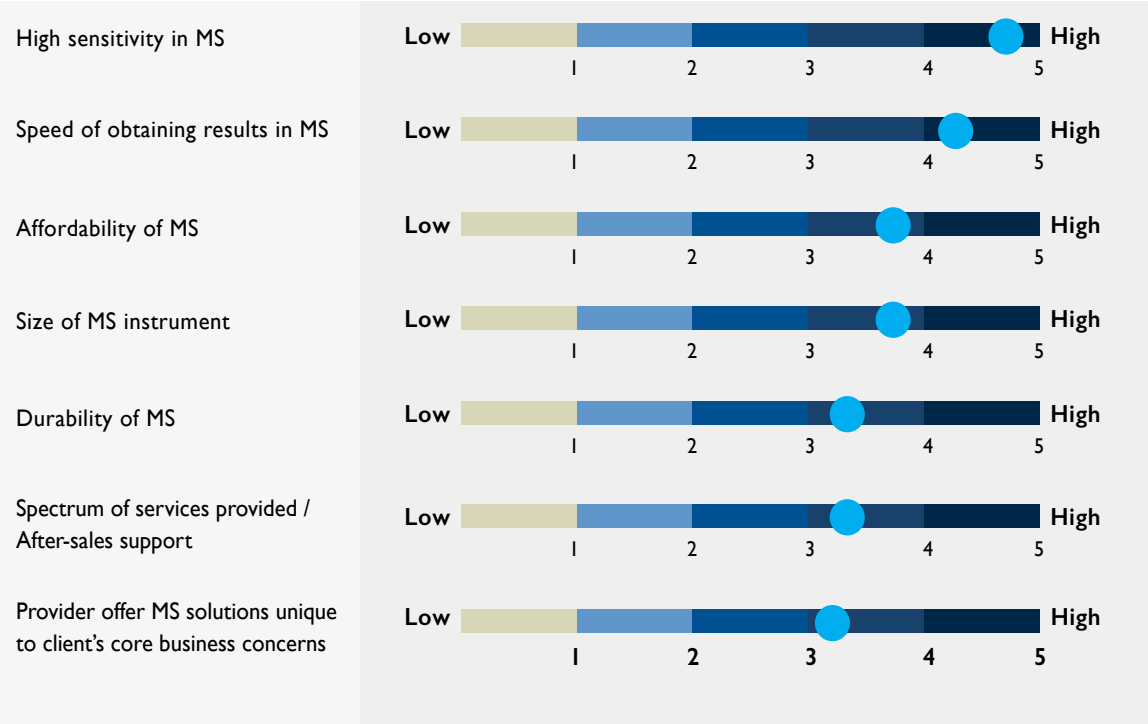
Ichiro Hirano, LCMS Product Manager at
Shimadzu Corporation

IV. Which Solution Provider Should You Choose?

With an increasing number of companies offering an ever-growing product portfolio of MS solutions, choosing one can be challenging.

Here are 7 essential indicators to consider as you screen potential providers:

Key Indicators That Clients Take Into Account When Choosing Providers



V. Shimadzu's Emergence as the Provider of UFMS

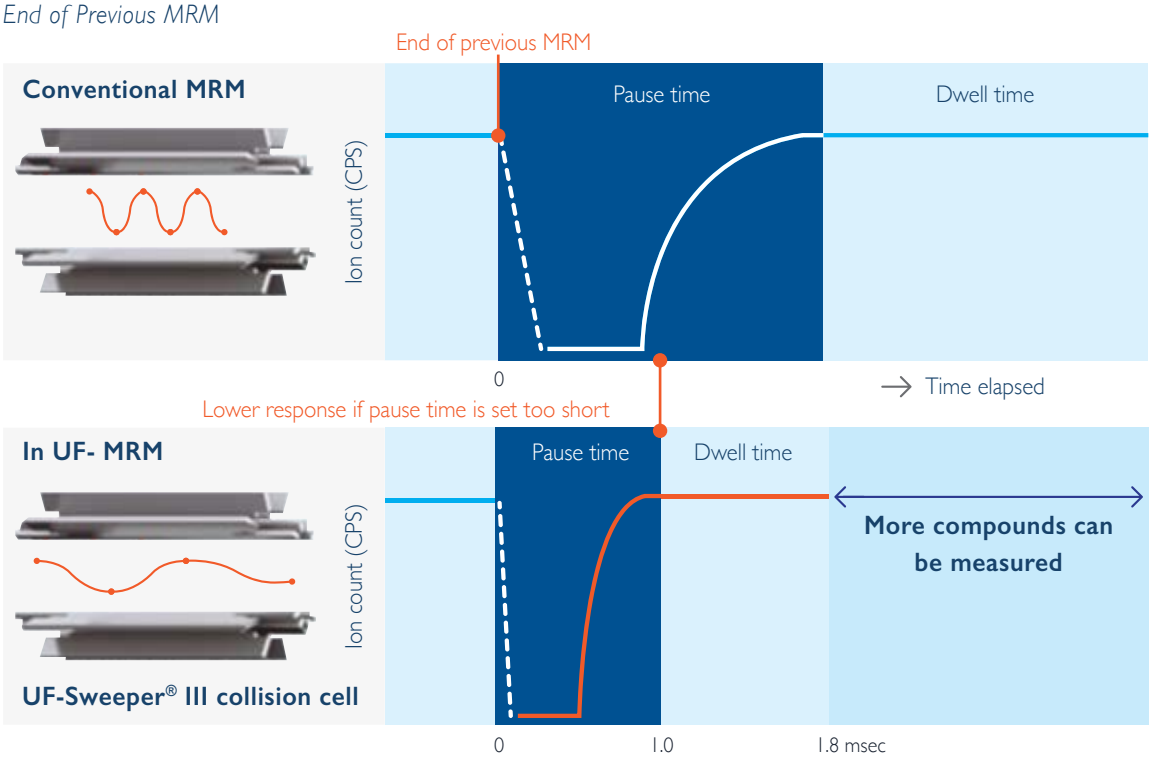
Triple quadrupole mass spectrometry platforms are universally recognized as robust, highly sensitive detection systems and differentiation within the market place presents significant technical challenges. By rethinking ion optic designs and data acquisition systems Shimadzu has now moved triple quadrupoles into a new analytical space by delivering class leading sensitivity and a higher capability in data quality through Ultra-Fast Mass Spectrometry (UFMS).

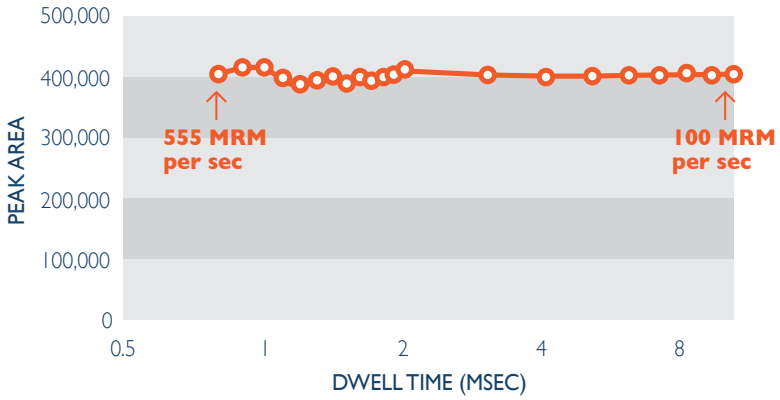
Delivering actionable data through UFMS

To explain how UFMS makes a real difference we need to review how a triple quadrupole mass spectrometer works. In conventional quadrupole mass spectrometry, ions are separated by applying oscillating RF and DC fields to the quadrupole. This process is very well described, however, the key driver in developing UFMS considered

achieving very high sensitivity and at the same time to expand the capability of the instrument. The approach taken by Shimadzu in redefining MRM analysis required developing a number of new technologies but perhaps the most significant was a redesign of the collision cell. Collision cells are designed to fragment precursor ions but this process takes time. This time frame is described by 2 parameters, the dwell time and pause time. The dwell time may be considered as the duty cycle of the instrument acquiring a data packet whilst the pause time enables the collision cell to clear all ions (avoiding cross talk) and reset the ion gate. To expand the capability of triple quadrupole mass spectrometry in large compound panels minimizing the pause time has a high impact. This impact must be considered in context, a very short pause time will result in a lower ion signal intensity and higher variability as the ion beam will not be stable. To help illustrate the science behind the design the figures below show the increased number of compounds that can be acquired without losing sensitivity using a new concept in collision cell geometry.

End of Previous MRM





The top figure highlights how ion signals can be lost if the pause time was set too short for an instrument's speed capability, and the data shown in the bottom figure demonstrates that this is not the case for Shimadzu UFMS. UFMS technology delivers a meaningful impact in high speed data acquisition and drives a new added value proposition to address the growing need of large-compound-panel testing in various fields, including food safety, environmental, and drug-of-abuse screening.

Technologies inside UFMS

Technical description of Shimadzu's TQ LC-MS

WORLD'S HIGHEST LEVEL OF SENSITIVITY AND ULTRAFAST SPEED (UFMS)

By rethinking the ion optics from the ion source to ion detector Shimadzu has engineered a new level of sensitivity and capability. There are several important innovations in the design.

Shimadzu's UF-Qarray, an ion guide based on high frequency quadrupole electric field, which has high central convergence

- The UF-Qarray is a highly efficient technology that converges the ion beam precisely into the quadrupole mass analyzer.
- It is a unique innovation that routinely delivers robust detection at very high sensitivities even with complex matrices at trace levels.

With a precisely focused ion beam generated by the Qarray the next challenge in triple quadrupole designs is to enhance the performance of the collision cell. Our approach was to radically change the way in which ions pass through the collision cell, dramatically increasing the speed of ions moving through the cell with very high CID efficiencies. The new technology not only delivers high sensitivities but greater capability with a maximum acquisition rate of 555 MRM/s.

To increase the capability further the electronics and power supply deliver polarity switching times of 5 milliseconds by default, creating new opportunities for acquiring both positive and negative mode data in the same analysis.

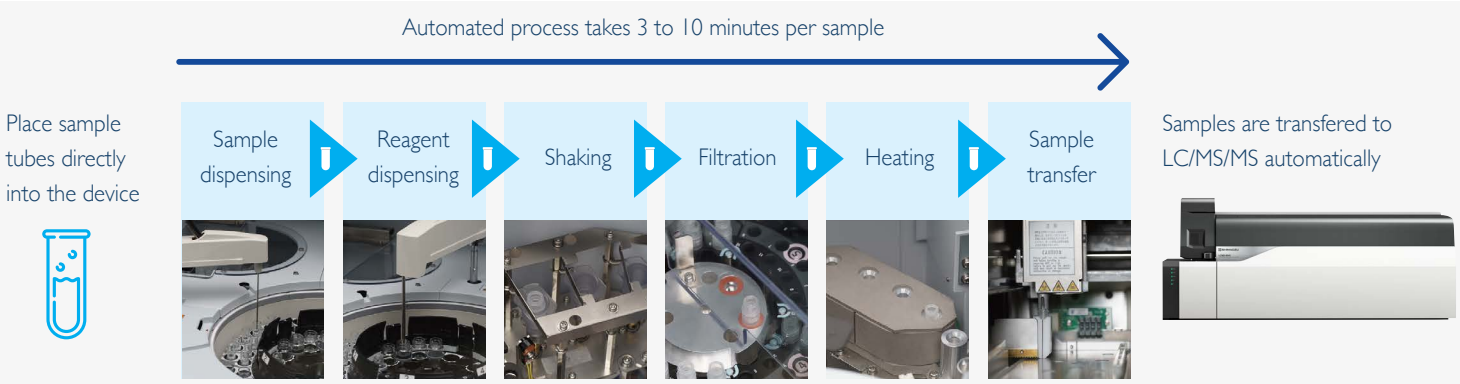
The end result is class leading sensitivity, higher data quality and 24/7 performance.

VI. Shimadzu's Visionary Innovation & Industry Impact

Shimadzu is a major influence on the global mass spectrometry market with a diverse product platform reflecting a proven passion to engineer new innovative technologies. Unlocking new science and developing unique solutions is part of our culture ranging from our Nobel Prize winning scientist Koichi Tanaka to developing new fundamental patents in mass spectrometry from our research divisions. Our passion to create unique solutions has opened new possibilities and opportunities by bringing together engineering ideas from our analytical and medical research groups creating innovations that really matter.

This approach is reflected in the development of automated 'sample to result' platform designed for routine clinical pathology laboratories. The CLAM-2000 (Clinical Laboratory Automated Module) integrated with LC-MS/MS works with multi-disciplinary teams in clinical laboratory environments. Clinical scientist's working with bar-coded blood samples and packaged methods can now approach LC-MS/MS as any other technique in the laboratory. The integration of CLAM LC-MS/MS system creates a "fire-and-forget" workflow, saving costs and improving productivity. It's already had a considerable impact for laboratories analyzing emergency samples and working with variable batch sizes where protocol adjustment is constantly needed.

Automated sample preparation process by CLAM-2000



The CLAM has several key advantages for routine clinical pathology laboratories, its flexibility (programming dispensing sequences), its ease of use (a simple user experience to work with multidisciplinary teams) and its throughput (35,000 tests/year). To match the needs of differing test panels, the CLAM works with any Shimadzu TQ-MS/MS (LCMS-8045, LCMS-8050 and LCMS-8060).

Shimadzu leads the market when it comes to customer experience

Making sure the support for applications, workflows and technologies is designed for each laboratory Shimadzu provides flexible in house training packages which can be shaped for every need. Understanding individual learning paths with focused content not only helps to improve productivity from the very start it helps to deliver a support program for the life cycle of the instrument. It's all part of the same thinking simply to share the same goals.

Customer Testimonials

Tandem mass spectrometry has become a leading technology used in clinical chemistry and has shown to be particularly sensitive and specific when used in new-born screening (NBS) tests. ***Shimadzu's UFMS permits a very rapid measurement of many metabolites*** *in different biological specimens, which enables us to identify possible treatable metabolic disorders especially when asymptomatic, and the benefits gained by this type of screening is now recognized worldwide*

GIANCARLO LA MARCA, PHARM SC. — Associate Professor of Clinical Chemistry, Department of Experimental and Clinical Biomedical Sciences, University of Florence, **Italy**

The automated LC-MS/MS has the potential to revolutionize the analysis in the lab*. It is possible to walk away from the instrument and let it perform hours and hours of work without intervention. So I was very impressed with the possibility the CLAM-2000 gave to our laboratory*

PROFESSOR PAOLO BRAMBILLA — Clinical Laboratories' Director, Milano-Bicocca University at Desio Hospital, Milan, **Italy**

Shimadzu LCMS (UFMS) systems brilliantly simplify the ionization technique in a high-speed, accurate and precise way, making it simple for us to present the best solution. ***We are extremely satisfied with the user-friendliness and versatility of their instruments****, allowing us to analyze complex chemical mixtures of a large variety*

PROFESSOR MARCOS EBERLIN — Thomson Mass Spectrometry Laboratory, Institute of Chemistry, University of Campinas, **Brazil**

*The most important parameters for an MS in the CRO industry is sensitivity. Shimadzu LCMS (UFMS) offers excellent sensitivity with reproducible results even for the most challenging molecules in complex matrices. W**ith the UFMS technology, Shimadzu has underlined the importance and positive impact that speed can have on your LCMS method design***

DR. SHIV PRAKASH — Chief Executive Officer, Synchron Research Services Pvt Ltd, **India**

*Shimadzu has been a leader in HPLC and UHPLC technologies for many years, providing reliable high-performance instruments and quality service support." "**Shimadzu is also a leader of the world when it comes to fast triple quadrupole mass spectrometer technology** and boasts the fastest scanning speeds and the most sensitive LC-MS. We are very happy to work with Shimadzu*

DR. RICHARD B.VAN BREEMAN — Professor, College of Pharmacy, University of Illinois at Chicago, **USA**

*LCMS-8050 from Shimadzu supports instrument parameters for over 300 pesticides which allows us to conduct the analysis and determine the level of pesticide residues efficiently. With our requirements being **well taken care of by the after-sales technical service team,** we are happy to continue working with Shimadzu*

DR. TANG TAO — Deputy Director of the Labs, Institute of Agricultural Products Quality Standard, Zhejiang Academy of Agricultural Sciences, **China**

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Frost & Sullivan, 331 E. Evelyn Ave., Suite 100
Mountain View, CA 94041

CONTACT INFORMATION:

Frost & Sullivan
100 Beach Road
#29-01/11, Shaw Tower
Singapore 189 702

Global
877.GoFrost
myfrost@frost.com

APAC
(65) 6890 0999
apacfrost@frost.com

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